Simulation and Analysis of Electromagnetic Showers in a Sampling Calorimeter

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July 17, 2025

Abstract

This report documents the detailed simulation of high-energy electromagnetic showers in a sampling calorimeter using the GEANT4 toolkit. We analyze the total, longitudinal, radial, and 2D transverse energy deposition profiles, and validate them against expected calorimetric behavior as established in experimental and theoretical literature.

1 Introduction

Calorimeters are essential detectors in high-energy physics (HEP) experiments, responsible for measuring the energy of incident particles. Sampling calorimeters consist of alternating layers of absorber and active materials. When a high-energy electron or photon enters, it initiates an electromagnetic shower—multiple generations of secondary particles primarily through bremsstrahlung and pair production [4, 7].

2 Simulation Setup

The simulation was developed using GEANT4 [1], a widely used toolkit in HEP detector design. The calorimeter geometry was implemented as a stack of absorber (lead) and scintillator layers. The primary beam consists of high-energy electrons incident perpendicular to the front face.

Each simulation event records energy deposits and hit positions in all layers, which are exported into ROOT files and analyzed with Python using the Uproot library.

3 Physics of Electromagnetic Showers

Electromagnetic showers evolve through a chain of bremsstrahlung and pair production processes, resulting in energy deposition that follows a longitudinal profile approximated by a Gamma distribution [6]. Transversely, the Molière radius defines the scale over which the shower spreads [7]. A well-designed calorimeter must balance granularity, depth, and resolution to optimize containment and measurement precision [5].

4 Simulation Observables and Analysis

Total Energy Deposition

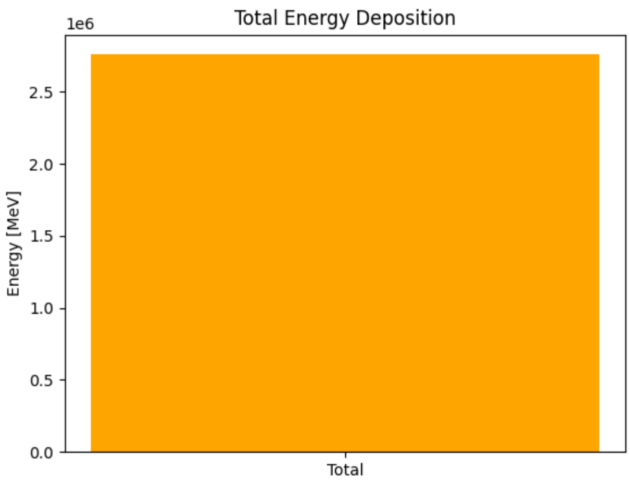

Figure 1: **Total Energy Deposition.** Histogram showing the total energy deposited in the calorimeter. A peak near the incident beam energy confirms energy containment and resolution.

Longitudinal Profile

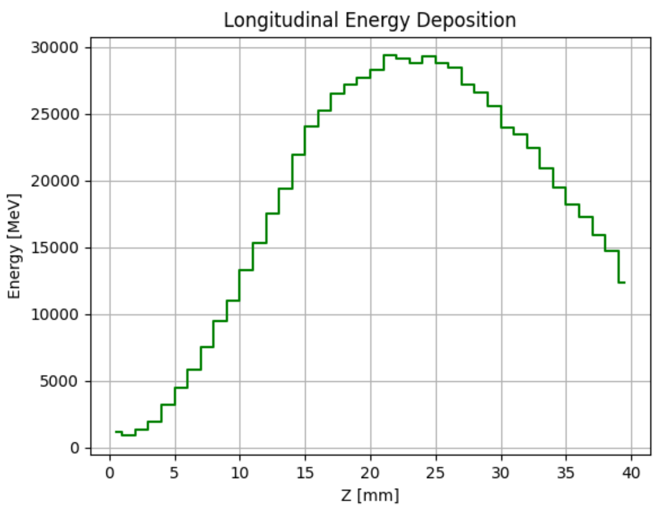

Figure 2: **Longitudinal Energy Deposition.** This profile tracks energy deposition layer-by-layer along the depth. It helps ensure shower containment and optimal calorimeter depth [6, 7].

Radial Profile

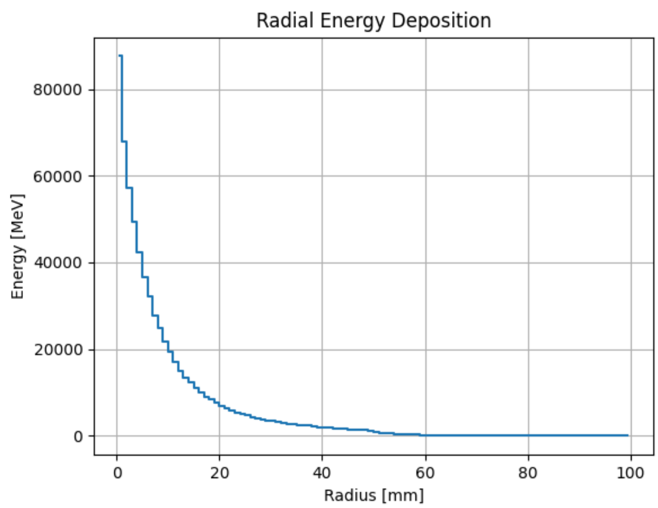

Figure 3: **Radial Energy Deposition.** Shows lateral shower spread. The energy drop-off informs us about the Molière radius and optimal transverse segmentation [7].

XY Energy Map

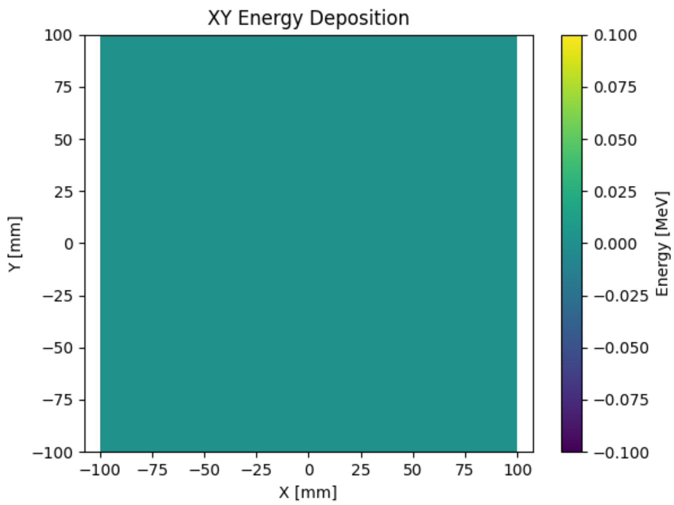

Figure 4: **XY Energy Deposition.** 2D map in transverse plane for clustering and beam alignment studies. Radial symmetry suggests proper shower formation.

5 Comparison to Real Experiments

Modern collider experiments like ATLAS and CMS employ advanced calorimeters with similar sampling designs [2, 3]. Our simulation setup reproduces the basic qualitative features of electromagnetic showers as seen in test beams and collider environments.

6 Usage Instructions

To reproduce this analysis, run the following Docker command:

```
docker pull ajaykumar49/calorimeter-dev:snapshot3
docker run -it -v $PWD:/work -w /work ajaykumar49/calorimeter-dev:snapshot3 /bin/bash

\section{Explore root file }

 Step 1: Open and Inspect Histograms
At the ROOT prompt:

// Check entries
hXY->GetEntries();       // should be > 0
hXY->Draw("COLZ");       // 2D XY plot

hRadial->Draw();         // radial energy profile
hLong->Draw();           // layer-wise deposition
hTotal->Draw();          // one-bin histogram: total E per event (sum)
If GetEntries() returns 0 for any histogram, it means it wasn't filled. But based on t

 Step 2: Inspect the TTree Hits
This is your per-event ntuple, which contains all hits:

Hits->Print();          // Show branch structure

Hits->Draw("edep");     // Draw all energy deposits
Hits->Draw("x:y", "edep > 0", "COLZ");   // x-y distribution of hits
You can also do:

Hits->Draw("sqrt(x*x + y*y)", "", "hist");  // radial distribution from tree
Hits->Draw("z", "", "hist");                // z distribution

 More: Quick Checks for Histogram Fill
If you're not seeing expected patterns:

cout << "XY Entries = " << hXY->GetEntries() << endl;
cout << "Radial = " << hRadial->GetEntries() << endl;
cout << "Long = " << hLong->GetEntries() << endl;
cout << "Total = " << hTotal->GetEntries() << endl;
 Summary
You now have:

Observable Object Name What It Shows
XY Map hXY Where in x-y plane energy was deposited
Longitudinal hLong Energy deposited per layer
Radial Profile hRadial Radial energy distribution (r = (x^2+y^2))
Total Energy hTotal Event-wise total energy deposit
Per-event Hits Hits Full ntuple with edep, x, y, z
```

References

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